A1460

GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT INITIATION

Date: September 26, 1972

Project Title: Consulting Services in Support of Patrol Frigate Electromagnetic Effectiveness Analysis Program

Project No.: A-1460 (S)

Project Director: Dr. C. E. Ryan

Sponsor: Autonetics Division, North American Rockwell Corporation

Effective . August 1, 1972 . . . . . Estimated to run until: March 31, 1973 . . . . . .

Type Agreement: P.O. No. 42MV-568343-X-855 (Subcontract under Navy Prime N00024-72-C-1444) . . . . Amount: $ 20,440.00* . . . . . .

*Total estimated cost; presently partially funded at $11,000 through October 31, 1972.

REPORTS REQUIRED: Monthly Progress Reports; Monthly Expenditure Reports; Preliminary Assessment Report; Refined Assessment Report; Final Report.

SPONSOR CONTACT PERSON:

Technical Matters
Mr. C. F. Weiss, Project Engineer
Autonetics Division,
North American Rockwell, Corp.
3370 Miraloma Avenue
Anaheim, California 92803

Contractual Matters
Mr. W. Grentz, Buyer
Autonetics Division, North American Rockwell
3370 Miraloma Avenue
Anaheim, California 92803

Defense Priority Rating: DO-A7 under DMS Reg. 1.

Assigned to . . Radar . . . . . Division

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GEORGIA INSTITUTE OF TECHNOLOGY
Engineering Experiment Station

PROJECT TERMINATION

Date October 15, 1973

PROJECT TITLE: Consulting Services in Support of Patrol Frigate Electromagnetic Effectiveness Analysis Program

PROJECT NO: A-1460

PROJECT DIRECTOR: Dr. C. E. Ryan

SPONSOR: Autonetics Division, Rockwell International Corporation, Anaheim, California

TERMINATION EFFECTIVE: ~~9-30-73~~

CHARGES SHOULD CLEAR ACCOUNTING BY: ~~9-30-73~~

CONTRACT CLOSEOUT ITEMS REMAINING: Final Invoice & Closing Documents
Final Report of Inventions
Government Prop. Inventory & Cert.
Classified Material Cert.

RADAR DIVISION

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GEORGIA INSTITUTE OF TECHNOLOGY
EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

14 September 1972

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Subject: Monthly Progress Report #1
"Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis
Contract No. A2MV-568343

Gentlemen:

In response to the NAR TWX of 1 August 1972 authorizing Georgia Tech to proceed, discussions with Mr. Charles Weiss and Dr. Harlowe Judson of Autonetics were held, and a definitive work statement agreed upon. This work statement consists of the following four tasks:

1. Assess the spillover radiation from the directive antennas, and determine the feasibility of simple antenna modifications to reduce any excessive spillover radiation. This assessment will be based upon electrical and physical characteristics of the antenna supplied to Georgia Tech. The information to be supplied will include antenna radiation patterns, antenna feed radiation patterns, and antenna configuration and placement data.

Schedule

Preliminary Assessment:	9/25/72
Refined Assessment:	1/1/73
Final Report:	2/1/73

2. Assess the effects of obstacle blockage upon the directive antenna main beam pattern performance. This assessment will consider optical blocking as the minimum degree of assessment. The effects of diffraction will be considered in the cases where diffraction data are available.

Schedule

Preliminary Assessment:	9/25/72
Refined Assessment:	1/1/73
Final Report:	2/1/73

3. Assess the main beam to main beam in band coupling between directive antennas. The effects of obstacles upon this main beam to main beam coupling will be included in the cases where data are available.

Schedule

Preliminary Assessment:	9/25/72
Refined Assessment:	1/1/73
Final Report:	2/1/73

4. Continue work on the above items with emphasis on the inclusion of the effects of obstacles in the pattern and coupling predictions.

Schedule

Completion: 4/1/73

This project has been assigned the internal Georgia Tech number A-1460. The following paragraphs summarize the progress made towards accomplishing the preliminary assessments scheduled in the first three tasks.

A. Progress Made and Milestones Reached

Preliminary drawings of the topside architecture of the Patrol Frigate have been obtained from VITRO Laboratories. Requests to VITRO Labs for the drawings, specifications and electrical characteristics of the directive antenna systems have been made. The electrical characteristics are to include the antenna patterns, feed antenna patterns, and physical characteristics of the antennas.

During the Contractor's meeting at VITRO Labs on the 7th and 8th of September, the availability of the above cited antenna information was checked with Mr. Raymond Prevary of VITRO. He stated that the material presently available would be forwarded immediately.

B. Problems Encountered and Action Taken

It appears that definitive data on the Mark-92 and SPS-55 antennas are not available. Mr. Prevary will try to obtain information on these systems. The SPS-49 data will be assumed to be equivalent to the data for the XN1 prototype antenna. If data on the Mark-92 and SPS-55 are not received in the next week, the antenna system specifications will be employed in the initial assessment, and qualified estimates as to the antenna patterns, etc., will be made.

C. Areas of Potential Difficulty

Two areas of potential difficulty are anticipated: First, the unavailability of needed data; and second, the possible changes in the topside configuration. VITRO Labs will attempt to obtain all needed information when it is identified. The configuration of the mast, whether it is to be an "open" or closed (i.e. "solid") structure has not yet been decided. This will affect the blockage and coupling estimates. If possible, estimates will be made for both configurations.

D. Activities Forecast

During the next period the preliminary spillover radiation, blockage, and coupling estimates will be made based upon the data provided by VITRO. These preliminary estimates will be completed by 25 September 1972.

E. Cost Estimates

The total cost (estimated to 31 August 1972) is $600.00. This rate of effort will be sharply increased during the next month when the necessary data are received. The total cost to the end of the contract is $20,778.00.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

CER:bp

Approved:

H. A. Ecker
Chief, Radar Division

GEORGIA INSTITUTE OF TECHNOLOGY
EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

5 October 1972

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis

Subject: Monthly Progress Report #2

Gentlemen:

A summary of progress on the contract for the period 14 September to 30 September follows.

A. Progress Made and Milestones Reached

The preliminary assessment of spillover radiation for the AN/SPS-49 radar antenna has been completed. It is concluded that the spillover radiation level in the vertical plane is excessive and that the spillover radiation in the azimuth plane is not as severe. The AN/SPS-49 may require antenna modifications for correction of spillover if the resultant coupling of radiation to other ship equipments is critical. The preliminary assessments of the blockage effects of the mast on the AN/SPS-49 and AN/SPS-55 radar antennas have also been completed. The results of this preliminary investigation are presented in detail in the report:

"Preliminary Assessment of the AN/SPS-49 and AN/SPS-55 Radar Antennas (U)", Report Confidential, C. E. Ryan Jr., and W. J. Storey, Jr., 25 September 1972

This interim technical report was sent to Autonetics on 29 September 1972.

B. Problems Encountered and Action Taken

Definitive radiation pattern data for the AN/SPS-49, AN/SPS-55, and Mark-92 antenna systems are still unavailable. The radiation patterns for

the AN/SPS-49 system and feed horn are required for a refined spillover assessment. VITRO has been informed of our need for these data. We will continue to base our estimates upon accepted antenna design practice until more definitive data are available.

C. Areas of Potential Difficulty

The areas of potential difficulty remain as previously stated in the Monthly Progress Report #1 of 14 September 1972. These areas of difficulty are the unavailability of needed data, and the possible changes in the topside configuration. Our preliminary estimates have been based upon the available data, and both "open" and "solid" mast structures have been assumed. Refined estimates will be based upon the available specifications for the antennas and ship configuration.

D. Activities Forecast

During the next period, the preliminary blockage estimates will be made for the Mark-92 antenna based upon the data available. Preliminary coupling estimates for the AN/SPS-49, AN/SPS-55, and Mark-92 antenna systems will be made. Efforts to further refine the blockage and coupling estimates will continue.

E. Cost Estimates

The total cost (estimated to 30 September 1972) is $3800.00. The total cost to the end of the contract is $20,778.00.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

Approved:

H. Allen Ecker
Chief, Radar Division

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2 November 1972

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 3

Gentlemen:

A summary of progress on the referenced contract for the period 1 October through 31 October follows.

A. Progress Made and Milestones Reached

The preliminary assessment of the blockage effects of both "solid" and "open" masts on the AN/SPS-55 and Mark-92 radar antennas has been completed. These results will be submitted to Autonetics during the next month. An assessment of the mast blockage effects on the STIR antenna has been initiated but is not yet complete.

Optical blockage data for the proposed Patrol Frigate topside configuration as of July 1972 have been generated using a computer program for shipboard siting of antennas. Samples of this data were delivered to Mr. Charles Weiss of Autonetics during the Patrol Frigate program review meeting on 24 October 1972. If specifically requested by Autonetics, additional optical blockage data can be generated.

B. Problems Encountered and Action Taken

Data for the STIR antenna has not yet been received. Georgia Tech has notified Vitro of this fact and Vitro has indicated that this data has been sent and should arrive within a week.

C. Areas of Potential Difficulty

The Patrol Frigate topside configuration has been changed since the preliminary assessments were made. The effects of the changes upon the assessments are being examined. Any significant modifications of the assessments will be reported to Autonetics.

Our present assessments of "open" mast blocking are based upon an estimate of four-inch diameter structural members for the mast construction. These assessments may be in error if the actual structural members are significantly different from this estimate. When the actual design of this structure is available, these estimates will be reviewed.

D. Activities Forecast

During the next period, it is anticipated that the STIR antenna data from Vitro will be received; based on the available data, the blockage estimates for the STIR antenna will be made. The effects of the changes in the topside configuration upon the previous estimates will also be examined and the preliminary coupling estimates will be refined.

E. Cost Estimates

The total cost through 30 September 1972 is $2,580.93. The total cost estimate through 31 October 1972 is $5,500.00. The total cost to the end of the contract is $20,778.00.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

Approved:

H. A. Ecker
Chief, Radar Division

GEORGIA INSTITUTE OF TECHNOLOGY
EXPERIMENT STATION 225 North Avenue, Northwest · Atlanta, Georgia 30332

28 November 1972

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 4

Gentlemen:

A summary of progress on the referenced contract for the period 1 November through 28 November follows.

A. Progress Made and Milestones Reached

The preliminary assessment of the blockage effects of "solid" and "open" masts on the pattern performance of the AN/SPS-49, AN/SPS-55, and Mark-92 radar antennas, based upon the proposed Patrol Frigate Topside Configuration of 17 July 1972, has been completed.

The in-band coupling between the AN/SPS-55 and Mark-92 (tracking and surveillance) antennas has been estimated.

These estimates are contained in a report to be submitted to Autonetics within about a week.

The data tables and algorithms used to estimate the blockage effects of solid masts upon the antenna pattern coverage are contained in a computer program at Georgia Tech. This program can be used to rapidly estimate the effects of future design changes on antenna coverage.

B. Problems Encountered and Action Taken

Data for the STIR antenna has not yet been released. Georgia Tech has notified Vitro of this problem several times. When this data is released, estimates of pattern performance and coupling will be made for this antenna.

C. Areas of Potential Difficulty

Because measured data for the blockage effects of open masts are not available, the present assessments of "open" mast blocking are based upon an approximate solution for aperture blocking by the feed support spars of a paraboloidal antenna. These estimates should be verified by measurements, but such measurements are outside the scope of the present contract. Therefore, future measurement programs should be considered for subsequent programs.

D. Activities Forecast

During the next period, efforts to extend and refine the blockage and coupling estimates will continue. Computer computations of the optical blockage for the revised topside configuration will be performed when a data deck is received from Atlantic Research Corporation. Automatic computations of the blockage effects upon the antenna pattern coverage will also be performed upon receipt of this data deck.

E. Cost Estimates

The total cost through October 1972 is $5,583.75. The total estimated cost through 30 November 1972 is $8,500.00. The total cost to the end of the contract is $20,778.00.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

CER:bp

Approved:

H. Allen Ecker
Chief, Radar Division

A-1460

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

11 January 1973

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 5

Gentlemen:

A summary of progress on the referenced contract for the period 1 December through 31 December follows.

A. Progress Made and Milestones Reached

The preliminary assessment of the blockage effects of both "solid" and "open" masts on the antenna pattern coverage performance of the AN/SPS-49, AN/SPS-55 and Mark-92 radar antennas has been completed. The preliminary assessment of the coupling between these antennas has been completed. These results were submitted to Autonetics as Interim Technical Report No. 2 on 8 December 1972. The preliminary assessment of the mast blockage on the STIR (SPG-60) radar antenna has been completed. This estimate will be sent to Autonetics within the next week.

In response to a request by Mr. Dennis Wright of Autonetics on 12 December 1972, estimates of the mast blockage effects for the integral IFF antennas of the AN/SPS-49 and Mark-92 radar systems were performed. A telephone conversation with Mr. Les Polisky of Atlantic Research Corporation was held to obtain engineering estimates for the IFF antenna dimensions, beam-widths and gains. On 14 December 1972, the AN/SPS-49 IFF blockage estimates were given to Mr. Dennis Wright over the telephone. The Mark-92 IFF estimates have not been completed due to a lack of engineering data on this antenna.

On 19 December 1972, Mr. Harlow Judson of Autonetics requested blockage estimates for a topside configuration which reversed the Mark-92 and STIR radar antenna locations. These preliminary estimates were performed and communicated to Mr. Harlowe Judson by telephone on 20 December 1972.

B. Problems Encountered and Action Taken

Data for the Mark-92 IFF antenna was not available. Consultations were held with Mr. Les Polisky of Atlantic Research Corporation to decide upon reasonable engineering estimates for the dimensions and electrical performance of the Mark-92 IFF antenna. The parameters agreed upon will be used in the estimates by Georgia Tech and Atlantic Research Corporation. The estimation of the blockage due to the AN/SPS-49 requires a detailed knowledge of the reflector structure. This information is not presently available. Information on the effects of multiple mast structures is not available. A limited literature search on multiple scattering is being conducted to obtain information pertaining to multiple masts.

C. Areas of Potential Difficulty

As mentioned in the monthly progress report No. 4, the "open" mast estimates are based upon an approximate solution for aperture blocking by the feed support members of a paraboloidal antenna. These estimates should be verified by measurements, but such measurements are outside the scope of the present program. Another area of difficulty is the blockage effects due to multiple "open" masts, such as on the Patrol Frigate. Presently only a "worst case" estimate is possible for this configuration. Some future effort should be directed toward refining the estimates for multiple mast configurations, either through a measurement program or a theoretical study.

Another area of potential difficulty is in the estimation of the blockage effects as a function of the elevation look angle of the antenna. Present estimates are based upon the 0^{o} elevation look angle data. A study of these blockage effects as a function of elevation look angle should be performed in the future.

D. Activities Forecast

During the next month efforts to extend and refine the blockage estimates will continue. Automatic computations of the blockage effects upon the radar antenna pattern coverage will be performed for the revised topside configuration. A limited literature search for information on scattering by two cylinders will be performed to determine whether refined estimates for the blockage due to two "open" masts can be made.

E. Cost Estimates

The total cost through November 1972 is $7,770.57. The total estimated cost through December 1972 is $10,000.00. The total cost to the end of the contract is $20,778.00.

Respectfully submitted,

Charles E. Ryan Jr.
Project Director

Approved:

H. A. Ecker
Chief, Radar Division

CER:bp

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

1 February 1973

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 6

Gentlemen:

A summary of progress on the referenced contract for the period 1 January through 31 January follows.

A. Progress Made and Milestones Reached

The effects of the AN/SPS-49 radar antenna reflector upon the Mark-92 and SPS-60 radar antenna performance were considered. These effects depend upon the type of construction used for the AN/SPS-49 antenna reflector. A rough estimate of the gain loss for the X-band radars when looking through the L-band reflector was made and given to Mr. Harlow Judson of Autonetics by telephone on 4 January 1973.

The effects of the fan antenna wires upon the AN/SPS-49 radar antenna were considered. It was concluded that these wires do not deteriorate the performance of the horizontally polarized radar antenna. They may have a slight effect on the vertically polarized IFF antenna. Design curves for wire grid structures available in the literature are being checked to substantiate these estimates.

The preliminary assessment of the blockage effects of the open mast on the AN/SPS-49 radar antenna was extended to estimate the effects of the structure at the top of the mast. The effects of this structure on the high-angle coverage of the AN/SPS-49 radar antenna were estimated and communicated to Mr. Harlowe Judson of Autonetics by telephone on 22 January 1973.

B. Problems Encountered and Action Taken

Data regarding the AN/SPS-49 radar antenna reflector construction is required in order to estimate possible blockage effects due to this large reflector. Mr. Harlowe Judson of Autonetics has been informed of this problem and it will be discussed with the AN/SPS-49 project engineers at the next program review meeting.

C. Areas of Potential Difficulty

As mentioned in the previous monthly progress reports, numbers 4 and 5, the "open" mast estimates are based upon an approximate solution for antenna aperture blocking. These estimates should be verified experimentally in the future. The blockage estimates for multiple open masts should also be refined and verified in the future.

Another area of potential difficulty is in the estimation of the blockage effect as a function of the elevation look angle of the antenna. At the present time a physical optics method is used to estimate the blockage due to complex structures mounted on the mast. These estimates should be refined in the future.

D. Activities Forecast

During the next month efforts to extend and refine the blockage estimates will continue. Dr. C. E. Ryan, Jr. of Georgia Tech will attend the Patrol Frigate Project Review Meeting on 5 and 6 February 1973. During this meeting, discussions will be held to determine goals for future activities in support of the program.

E. Cost Estimates

The total cost through January 1973 is $18,121.33. The total cost to the end of the contract is $20,778.00.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

CER:sp

Approved:

H. Allen Ecker
Chief, Radar Division

A-1460

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

5 March 1973

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 7

Gentlemen:

A summary of the progress on the referenced contract for the period 1 February through 28 February 1973 follows.

A Progress Made and Milestones Reached

Dr. C. E Ryan Jr. of Georgia Tech attended the Patrol Frigate Project Review Meeting on 5 and 6 February 1973. A summary of the Georgia Tech results for the antenna coupling and blockage effects was presented. Technical discussions were held to determine areas where further technical effort is needed in support of the program. Technical discussions were also held with personnel of the Naval Research Laboratory concerning the blockage effects of the mast and the topside structure upon the SPS-49 radar antenna. The independent NRL and Georgia Tech estimates, for these blockage effects, were found to be in agreement.

In response to a request by Harlowe Judson of Autonetics, the blockage estimates for the SPS-49 antenna were extended to predict the high angle pattern performance as a function of azimuth look angles in the angular region near the mast and topside platform. These results were given to Autonetics by telephone on 22 February.

B. Problems Encountered and Action Taken

Some questions were raised by Autonetics on the antenna pattern performance

of the SPS-49 prototype antenna. As the blockage estimates are sensitive to antenna pattern performance, telephone conversations were held with R. J. Adams and R. Crisler of NRL and Mr. William Shrader of Raytheon concerning the performance of the SPS-49 antenna prototype. Based upon these conversations, it was determined that a reasonable level of confidence can be placed in the estimates made for this antenna.

C. Areas of Potential Difficulty

The blockage estimates for the SPS-49 antenna do not consider the effects upon the antenna sidelobes which are caused by reflection phenomena. At the present time no data on these effects is available. This subject should be considered in the future.

D. Activities Forecast

During the next month a report summarizing the Georgia Tech results will be prepared. Also a set of "rules of thumb" for the topside siting of the directional radar antennas will be developed.

E. Cost Estimates

The total estimated cost through February 1973 is $19,200.00. The total cost to the end of the present contract is $20,440.00.

Respectfully submitted,

Charles E. Ryan Jr.
Project Director

CER:lg

Approved:

H. Allen Ecker
Chief, Radar Division

A-1460

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

3 April 1973

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 8

Gentlemen:

A summary of the progress on the referenced contract for the period 1 March through 31 March 1973 follows.

A. Progress Made and Milestones Reached

In response to a request by Autonetics, a summary of "Rules of Thumb" for Antenna Siting for the PF was prepared and given to Mr. Frank E. Ferrante of Atlantic Research Corporation via telephone on 6 March 1973. Specific siting criteria for the AN/SPS-49, AN/SPS-55, Mk-92 and STIR radar antennas were included in the 6 March 1973 summary.

A summary of the technical assessments performed during the period 31 August 1972 to 22 March 1973 has been prepared. This report will be sent to Autonetics for security review and approval within the next week.

B. Problems Encountered and Action Taken

No problems were encountered during this reporting period.

C. Areas of Potential Difficulty

Georgia Tech has been requested to assess the performance of the PF ECM antennas with respect to pattern coverage. Antenna pattern data for these antennas will be required for this assessment. Some required data may not be available.

D. Activities Forecast

During the next month the available data on the PF ECM antennas will be collected and reviewed. The assessment of the ECM antenna coverage will be intiated.

E. Cost Estimates

The total estimated cost through March 1973 is $21,500.00. The total estimated cost to the end of the contract is $40,376.00.

Respectfully submitted,

Charles E. Ryan Jr.
Project Director

CER:lg

Approved:

H. Allen Ecker
Chief, Radar Division

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332
2 May 1973

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 9

Gentlemen:

A summary of the progress on the referenced contract for the period 1 April through 30 April 1973 follows.

A. Progress Made and Milestones Reached

The summary report for the period of 31 August 1972 to 22 March 1973 has been submitted to Autonetics for security review and approval. This summary report discusses the estimation techniques and the assessments of the antenna pattern and coupling performance of the PF microwave radar antenna systems.

The assessment of the pattern coverage of the PF ECM antennas has been initiated. Antenna data for the AS-1023/SLR and AS-1174/SLR antennas have been obtained. Additional pattern data will be required for these ECM antennas for future refined assessments.

B. Problems Encountered and Action Taken

More detailed data on the ECM antennas are required. A request for these data has been forwarded to VITRO.

C. Areas of Potential Difficulty

No areas of potential difficulty are foreseen at this time.

D. Activities Forecast

The assessment of the ECM antenna coverage will be continued.

E. Cost Estimates

The total estimated cost through April 1973 is $22,000.00. The total estimated cost to the end of the contract is $40,376.00.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

CER:lg

Approved:

F. L. Cain
Technical Area Manager,
EM Effectiveness

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7 June 1973

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 10

Gentlemen:

A summary of the progress on the referenced contract for the period 1 May through 31 May 1973 follows.

A. Progress Made and Milestones Reached

A report entitled "Preliminary Assessment of Multiple Mast Blocking Effects and Elevation Angle Performance of the MK-92 and STIR (SPG-60) Radar Antennas" (U) has been prepared. This report will be submitted to Autonetics for security review and approval within the next week. This report discusses multiple mast blocking estimation techniques and the effects of the multiple mast blocking upon the Patrol Frigate Directive radar antennas. The report also presents preliminary estimates of the blocking effects upon the MK-92 and STIR (SPG-60) as a function of elevation angle.

Work is continuing on the development of assessments for the pattern coverage performance of the PF ECM antenna set. Additional information on the pattern characteristics is required.

B. Problems Encountered and Action Taken

Detailed information on the ECM antennas is required. Requests for these data have been forwarded to VITRO and Autonetics.

C. Areas of Potential Difficulty

Due to the complexity of the top-of-the-mast platform structures and antennas, an accurate assessment of the elevation pattern performance of the MK-92 and STIR (SPG-60) antennas may not be possible, because complete data are not available. However, efforts will be made to refine the preliminary assessments through the use of available data.

D. Activities Forecast

The assessment of the directive antenna elevation pattern performance and of the ECM antenna coverage will be continued.

E. Cost Estimates

The total estimated cost through May 1973 is $24,045.00. The total estimated cost to the end of the contract is $40,376.00.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

CER:sp

Approved:

F. L. Cain
Technical Area Manager
EM Effectiveness

A-1460

ENGINEERING EXPERIMENT STATION

GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

5 July 1973

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 11

Gentlemen:

A summary of the progress on the referenced contract for the period 1 June through 30 June 1973 follows.

A. Progress Made and Milestones Reached

A report entitled "Preliminary Assessment of Multiple Mast Blocking Effects and Elevation Angle Performance of the MK-92 and STIR (SPG-60) Radar Antennas" (U) has been submitted to Autonetics for security review and approval. This report discusses multiple mast blocking estimation techniques and the effects of the multiple mast blocking upon the Patrol Frigate directive radar antennas. The report also presents preliminary estimates of the blocking effects upon the MK-92 and STIR (SPG-60) as a function of elevation angle.

Work is continuing on refining the assessment of the elevation angle pattern performance of the radar antennas and on the development of assessments for the

pattern coverage performance of the PF ECM antenna set. Additional information on the pattern characteristics of the ECM antennas is required.

B. Problems Encountered and Action Taken

Detailed information on the ECM antennas is required. Requests for these data were forwarded to VITRO and Autonetics. As of this date, detailed data on these antennas have not been received.

C. Areas of Potential Difficulty

Due to the complexity of the top-of-the-mast structures, accurate assessment of the elevation pattern coverage of the radar antennas may not be possible. This structural complexity also complicates the assessment of the pattern performance of the ECM antennas. Efforts will be made to refine the crude preliminary assessments by devising simple scattering models for the complex structures.

D. Activities Forecast

The assessment of the directive antenna elevation pattern performance and of the ECM antenna coverage will be continued.

E. Cost Estimates

The total estimated cost through June 1973 is $26,000.00. The total estimated cost to the end of the contract is $40,376.00.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

CER:lg

Approved:

F. L. Cain
Technical Area Manager
EM Effectiveness

A-1460

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332
6 August 1973

Autonetics Division
North American Rockwell Corporation
P. O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 12

Gentlemen:

A summary of the progress on the referenced contract for the period 1 July through 31 July 1973 follows.

A. Progress Made and Milestones Reached

An algorithm for determining the diffraction effects of the top-of-the-mast platforms on the antenna pattern coverage of the ECM antennas has been programmed and is presently being tested. Information on the pattern characteristics of the ECM antennas is required before estimates for the pattern coverage can be made.

B. Problems Encountered and Action Taken

Requested information on the ECM antenna patterns has not been received from either VITRO or Autonetics. Further attempts will be made to obtain this information.

Refined estimates for the elevation pattern coverage of the MK-92 and STIR (SPG-60) radar antennas are not possible at this time due to the complexity of the top-of-the-mast structures and a lack of either measured or

theoretical data. Basic research needs to be performed to obtain data which may be used for future estimates of the blockage effects of complex structures.

C. Areas of Potential Difficulty

The complexity of the top-of-the-mast structure precludes estimation of the blockage effects as a function of antenna elevation pointing angle. Crude estimates may be possible if a suitable simple scattering model can be devised to represent the complex structure.

D. Activities Forecast

A Final Report on Georgia Tech activities on this contract will be prepared and submitted during the next month.

E. Cost Estimates

The total estimated cost through July 1973 is $29,000.00. The total estimated cost to the end of the contract is amended to be $32,000.00.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

CER:lg

Approved:

Fred L. Cain
Technical Area Manager
EM Effectiveness

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

5 September 1973

Autonetics Division
Rockwell International Corporation
P.O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 13

Gentlemen:

A summary of the progress on the referenced contract for the period 1 August through 31 August 1973 follows.

A. Progress Made and Milestones Reached

A Final Report on the Georgia Tech activities in support of the Patrol Frigate Electromagnetic Effectiveness Analysis has been completed and forwarded to Autonetics. This report lists the technical reports submitted, the meetings in which Georgia Tech personnel participated, and the methods employed in the antenna performance assessments.

B. Problems Encountered and Action Taken

No technical problems were encountered during the reporting period.

C. Areas of Potential Difficulty

The complexity of the top-of-the-mast structure precludes estimation of the blockage effects as a function of antenna elevation pointing angle. Crude estimates may be possible if a suitable simple scattering model can be devised

to represent the complex structure.

D. Activities Forecast

The documentation of the Georgia Tech assessments will continue during the next month.

E. Cost Estimates

The total estimated cost through August 1973 is $30,000.00. The total estimated cost to the end of the contract is $32,000.00.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

CER:bs

Approved:

Fred. L. Cain
Technical Area Manager
EM Effectiveness

A-1460

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

2 October 1973

Autonetics Division
North American Rockwell Corporation
P.O. Box 4163
3370 Miroloma Avenue
Anaheim, California 92803

Attention: Mr. W. Grentz

Reference: Contract No. A2MV-568343

Title: "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis"

Subject: Monthly Progress Report No. 14

Gentlemen:

A summary of the progress on the referenced contract for the period 1 September through 30 September 1973 follows.

A. Progress Made and Milestones Reached

The algorithm for determining the diffraction effects of the top-of-the-mast platforms on the antenna pattern coverage of the ECM antennas has been developed. Information on the pattern characteristics of the ECM antennas is required before estimates for pattern coverage can be made. This algorithm will be available for future use on shipboard antenna analysis. Documentation of the results of the analysis was completed during this reporting period.

B. Problems Encountered and Action Taken

No problems were encountered during the reporting period.

C. Areas of Potential Difficulty

No areas of potential difficulty were defined during the reporting period.

D. Activities Forecast

Dr. Ryan of Georgia Tech will attend the final PF review meeting during October.

E. Cost Estimates

The total estimated cost through September 1973 is $31,000.00. The total estimated cost to the end of the contract is amended to be $32,000.00.

Respectfully submitted,

Charles E. Ryan, Jr.
Project Director

CER:jb

Approved:

Fred L. Cain
Technical Area Manager
EM Effectiveness

LIBRARY DOES NOT HAVE INTERIM REPORTS 1-3. CLASSIFIED SECRET.

FINAL REPORT

on

CONSULTING SERVICES IN SUPPORT OF THE PATROL FRIGATE ELECTROMAGNETIC EFFECTIVENESS ANALYSIS PROGRAM

C. E. Ryan Jr. and R. D. Nevels Jr.

30 August 1973

Prime Contract No. N00024-72-C-1444
Subcontract No. A2MV-568343

for

Autonetics Division
Rockwell International Corporation

by

Radar Division
ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
Atlanta, Georgia 30032

FINAL REPORT

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CONSULTING SERVICES IN SUPPORT OF THE PATROL FRIGATE ELECTROMAGNETIC EFFECTIVENESS ANALYSIS PROGRAM

C. E. Ryan Jr. and R. D. Nevels Jr.

30 August 1973

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for

Autonetics Division
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by

Radar Division
ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
Atlanta, Georgia 30032

FOREWARD

The research on this program was carried out by personnel of the Radar Division of the Systems and Techniques Department, Engineering Experiment Station at the Georgia Institute of Technology, Atlanta, Georgia 30332. Dr. C. E. Ryan Jr. served as Project Director. The program was sponsored by the Autonetics Division of Rockwell International Corporation under Subcontract No. A2MV-568343 (Prime Contract No. N00024-72-C-1444), and was designated by Georgia Tech as Project A-1460. This final report covers the period between 31 August 1972 and 30 August 1973.

The work performed was made possible by the combined efforts of the staff of the Marine Systems Group at Autonetics and the Radar Division at Georgia Tech. The contributions of Charles Weiss and Harlowe Judson of Autonetics and of F. L. Cain and W. J. Storey of Georgia Tech are gratefully acknowledged.

Charles E. Ryan Jr.
Project Director

Approved:

F. L. Cain

Technical Area Manager
Electromagnetic Effectiveness

ABSTRACT

The objective of the consulting activities on this project is the assessment of the effects of the proposed Patrol Frigate topside structure on the performance of the directive radar antennas. These assessments include the effects of mutual coupling between antennas, gain loss as a function of antenna look angle, and sidelobe deterioration due to aperture blocking. The effects of spillover radiation on antenna performance have also been assessed. This report describes the activities performed on the above assessments during the contract period.

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LIST OF FIGURES

SECTION I
INTRODUCTION

This report summarizes the consulting activities of the Radar Division, Systems and Techniques Department of the Engineering Experiment Station at Georgia Institute of Technology in support of the Patrol Frigate Electromagnetic Effectiveness Analysis Program. The tasks assigned to the Radar Division are listed in Section II and concerned assessment of spillover radiation from the directive radar antennas, and the assessment of the effects of the ship topside structure on the performance of the directive radar antennas. The effects of the ship topside structure upon the antenna gain, antenna sidelobes, and the mutual coupling between directive antennas were estimated by using available measured data and by standard theoretical techniques in cases where measured data were not available. The estimation techniques which were employed are described in the Appendixes I to III of this report.

The detailed estimates of the directive radar antenna performance are contained in the technical reports submitted during the contract. This information was used by Autonetics in the computer simulation of the radar system performance. These reports are listed in Section III and in the Patrol Frigate Mission Oriented File prepared by the Rockwell International Corporation.

The experience gained by participation in this program has indicated several areas where research is needed to develop more accurate estimation techniques. Recommendations for research which will aid in future EM analysis programs are presented in Section VI.

SECTION II

TASKS ASSIGNED TO GEORGIA TECH

Tasks were assigned to Georgia Tech under the Autonetics Subcontractor Memoranda of 5 September 1972 and of 25 January 1973. The following tasks were assigned under the Memoranda of 5 September 1972.

Memorandum No. SM 72-GIT-1

Assess the spillover radiation from the directive antennas, and determine the feasibility of simple antenna modifications to reduce any excessive spillover radiation. This assessment will be based upon electrical and physical characteristics of the antenna supplied to Georgia Tech. The information to be supplied will include antenna radiation patterns, antenna feed radiation patterns, and antenna configuration and placement data.

Memorandum No. SM 72-GIT-2

Assess the effects of obstacle blockage upon the directive antenna main beam pattern performance. This assessment will consider optical blocking as the minimum degree of assessment. The effects of diffraction will be considered in the cases where diffraction data are available.

Memorandum No. SM 72-GIT-3

Assess the main beam to main beam in band coupling between directive antennas. The effects of obstacles upon this main beam to main beam coupling will be included in the cases where data are available.

Upon completion of the tasks listed above, the following additional tasks were specified in the Subcontractor Memoranda of 25 January 1973.

Memorandum No. SM 73-GIT-1

Assess the main-beam to main-beam in-band coupling between directive antenna pairs for alternate antenna arrangements specified by Autonetics. Obstacle effects shall be included whenever appropriate data are available.

Memorandum No. SM 73-GIT-2

Assess the effects of obstacles on radar beam pattern performance. This assessment will include non-zero elevation angles and estimates of main beam/side lobe ratios as special cases.

Memorandum No. SM 73-GIT-3

Investigate applicability of present assessment technique for radar beam pattern performance, possibly including limited measurements on structural obstacles similar to those on PF.

The tasks specified by Memoranda 73-GIT-1 and 73-GIT-2 were completed for the cases where appropriate electromagnetic analyses and data were available. At the direction of Autonetics the task specified by Memorandum 73-GIT-3 was not pursued becuase of a reduction in the funding of the Georgia Tech effort.

SECTION III

REPORTS

In response to the tasks assigned to Georgia Tech for "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis Program," the following reports were submitted to Autonetics. A brief description of the content of each report is given.

1. C. E. Ryan Jr. and W. J. Storey Jr., "Preliminary Assessment of the AN/SPS-49 and AN/SPS-55 Radar Antennas," 25 September 1972

   This report presents the results of a preliminary assessment of the blockage effects of both solid and open mast structures on the antenna coverage performance of the AN/APS-49 and AN/SPS-55 radar antennas.

2. C. E. Ryan Jr., W. J. Storey Jr., and R. D. Nevels Jr., "Preliminary Assessment of the AN/SPS-49, AN/SPS-55 and MK-92 Radar Antennas," 30 November 1972

   This report presents estimates of the spillover radiation of the AN/SPS-49 radar antenna, assessments of the blockage effects of open and solid mast structures upon the radar antennas, and estimates of the in-band, main-beam to main-beam coupling between the radar antennas.

3. C. E. Ryan Jr., "Consulting Activities in Support of the Patrol Frigate Electromagnetic Effectiveness Analysis - Technical Letter," 11 January 1973

   This letter presents additional open and solid mast blockage estimates for the AN/SPS-49 (IFF) and SPG-60 radar antennas. Blockage effects as a function of elevation angle for the AN/SPS-49 antenna are discussed and the blockage effects on the AN/SPS-49 antenna sidelobes are estimated. In-band coupling estimates for the SPG-60 antenna are also discussed.

4. C. E. Ryan Jr., W. J. Storey Jr., and R. D. Nevels Jr., "Summary Report Covering the Period of Initiation of 31 August 1972 to 22 March 1973".

This report summarizes all of the assessments to date of spillover radiation, blockage effects of solid and open masts on antenna performance, and in-band, main-beam coupling between the directive antennas. The antennas covered include the AN/SPS-49, AN/SPS-49 (IFF), AN/SPS-55, MK-92, and the SPG-60.

5. C. E. Ryan Jr., "Preliminary Assessment of Multiple Mast Blocking Effects and Elevation Angle Performance of the MK-92 and STIR (SPG-60) Radar Antennas." 29 May 1973

This report discusses techniques for estimation of the blockage effects of multiple masts on radar antenna coverage. Techniques for estimating blockage effects as a function of antenna elevation scan angle are discussed and assessments of elevation angle performance based upon optical blockage plots are presented for the MK-92 and SPG-60 radar antennas. Blockage plots based upon optical analysis for the AN/SPS-49, MK-92 and SPG-60 antennas are included.

SECTION IV

MEETINGS

The consulting activities in support of the PF Electromagnetic Effectiveness Analysis Program included participation in PF Project Review Meetings. Georgia Tech participated in the following PF Project Review Meetings.

Date	Location	Georgia Tech Attendee
6 July 1972	NAVSEC Hyattsville, MD.	F. L. Cain
7-8 Sept. 1972	VITRO Labs Silver Spring, MD.	C. E. Ryan Jr.
23-24 Oct. 1972	Autonetics Anaheim, Calif.	C. E. Ryan Jr.
5-6 Feb. 1973	Atlantic Research Corp. Alexandria, VA.	C. E. Ryan Jr.

During the meetings of 23-24 October 1972 and 5-6 February 1973 Dr. C. E. Ryan Jr. presented oral briefings on the results of the Georgia Tech consulting efforts.

SECTION V

SUMMARY

The techniques which were applied to estimate the effects of the ship topside structure are presently limited in their application. The specific limitations have been discussed in the previously mentioned technical reports. These limitations are due to the complexity of the ship topside structures and the large number of structures occurring on the ship. Also, these structures are typically located in the near zone of the antennas which further complicates the analysis or experimental characterization of their effects on antenna performance.

In the assessment of the directive radar antenna performance of the PF, both simple theoretical models and measured data for simple obstacles have been used. At the present time, these techniques are limited due to the lack of comprehensive theoretical analyses or extensive measured data for near-zone scattering by complex obstacles. The gross estimates of the blocking effects of these complex obstacles are made by assuming that these effects are approximated by scattering due to relatively simple obstacles.

The approximate approaches used herein are valuable for the assessment of the gross effects of the structures upon the antenna gain and sidelobe levels. If precise, high-confidence level assessments are required, additional research is needed to develop extended methods of assessment. A possible approach would utilize statistical methods to characterize the complex scatterers. A statistical approach would provide the analyst with the magnitude of the possible deviation of the performance from the mean value.

The assessments of the approximate antenna performance for the PF topside configuration are useful in modelling the electromagnetic effectiveness of the radar systems. In making the assessments a pessimistic approach has been used so that an approximation to the "worst case" performance could be arrived at. In future programs, more accurate assessment techniques and measured data may permit optimum topside configurations to be derived. However, additional research is required before this goal can be attained.

In summary, the tasks assigned to the Radar Division have been performed and the results have been submitted to Autonetics for use in the EM analysis. The submitted reports, which fulfill the requirements of the subcontract, present the techniques used and the detailed results obtained.

SECTION VI

RECOMMENDATIONS

In order to advance the state-of-the-art of the assessment of the ship topside structure upon the electromagnetic performance of the directive radar antennas it is recommended that research be undertaken in the following areas:

1. The accuracy of the present estimates should be checked against measurements recorded under controlled conditions to determine areas where the present approximate assessment techniques are inaccurate, and to identify the sources of error. Modifications of the present techniques to obtain more accurate results should then be undertaken.

2. The blockage effects of complex obstacles such as "open masts" should be determined experimentally for several typical antenna types to develop baseline data for future assessments.

3. The present data base for blockage effects of solid mast geometries should be extended by measurement of additional data and by development of theoretical algorithms which will permit computation of blockage effects of solid obstacles in the near zone of specified antennas.

4. Additional measurements and theoretical analysis of the effects of obstacles upon the sidelobe structures of radar antennas are required.

5. Efforts should be made to develop comprehensive statistical models for the scattering effects of collections of complex obstacles.

The above recommendations for required future research effort are not exhaustive but are indicative of the general areas where research is needed to refine the assessment techniques. Since basic research was outside the scope of the present subcontract no efforts were made to extend or refine the data base or theoretical techniques during the program. However the above listed topics indicate the areas where work is necessary in order to refine the assessment techniques for application in future programs.

APPENDIX I

TECHNIQUES FOR ESTIMATION OF MAST BLOCKAGE

Estimates for main beam one-way gain reduction were performed for both the solid cylindrical and square masts and for the "open" mast structure composed of a tower of metallic spars. A different estimation technique was used for each of these two cases.

1. Open Mast Blockage Estimation Technique

The open mast blockage technique was originally developed for estimating the loss in antenna gain due to feed support member blocking (1). The technique is based on the computation of the percentage of the antenna aperture which is blocked by the metallic member. This technique was adapted for estimating the blockage due to "open mast" structures by assuming that the equivalent blocked area due to the open structure could be equated to the blockage area of a feed support in the antenna aperture. This assumption is reasonable if the distance from the structure to the antenna is less than approximately 0.05 of the far zone range (R (far zone) $= 2D^2/\lambda$, where D = antenna diameter, λ = wavelength), and if the percentage of the blocked area does not exceed approximately 30%. In order to use the open mast blocking technique, any antenna aperture that is not circular was equated to a circular aperture having the same area and the area blocked by the mast structure was normalized as shown in Figure 1.

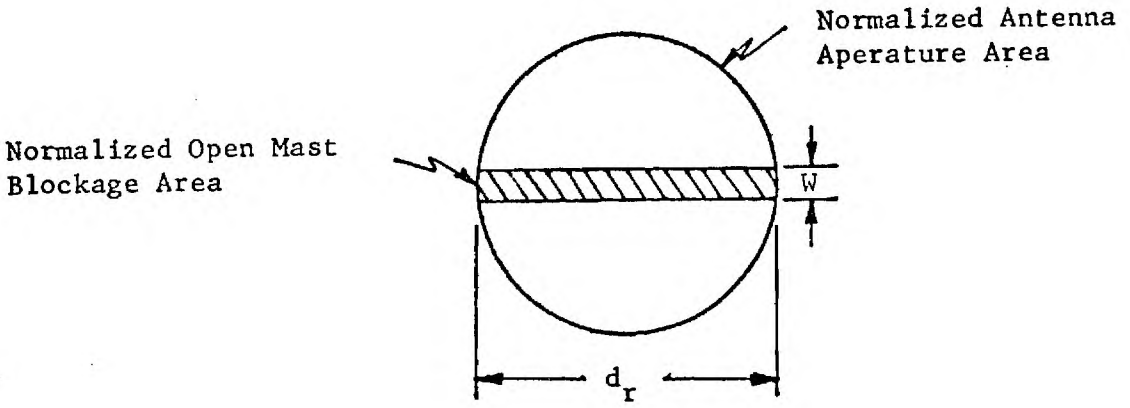


Figure 1 Equivalent Aperture Blocking Model.

The area blocked by the mast is represented by a strip of width W and length d_r equal to the equivalent circular aperture diameter. The approximation is valid for $W \ll d_r$ which limits this method to cases where the blockage area is less than approximately 30% of the aperture area. With the antenna aperture area and blockage area represented in this form, a gain loss estimate is made using the following gain reduction formula.

$$10 \log_{10} \left(\frac{G_B}{G_o} \right) = 20 \log_{10} \left(1 - 1.55 \frac{W}{d_r}\right) \text{ dB}, \qquad (1)$$

where, G_B = power gain with blockage, and

G_o = power gain without blockage.

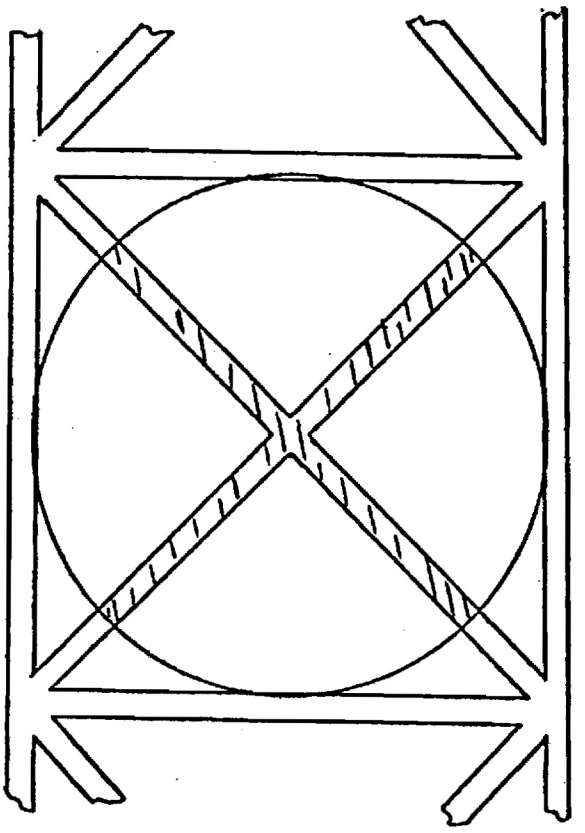
In this method one assumes a tapered aperture distribution, and an aperture efficiency for the blocked area based upon an illunination taper of the form $(1 - r^2)$, where r is the normalized radius.

A computer program was written, using the trapzaoidal integration method for determing the open mast blocking parameters. In this estimation the open mast configuration shown in Figure 2 was assumed.

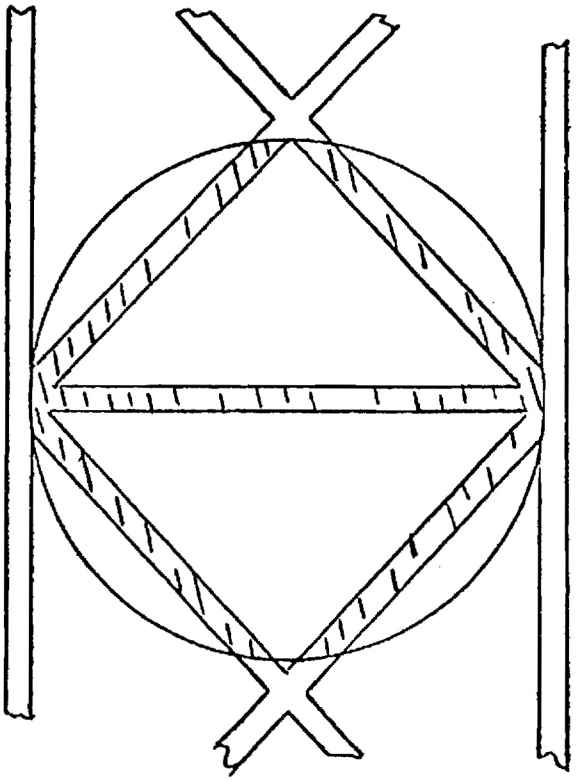
Variation will occur in the open mast blocking estimate depending upon which section of the mast structure is aligned on the electrical axis of the antenna. Figure 2 shows an example of the best (least aperture blocked) and worst (most aperture blocked) cases for a circular aperture antenna aligned with the center of an open mast. In estimating gain loss due to open mast blockage both "best" and "worst" blockage cases are considered to establish bounds on the gain loss.

In this blockage estimation technique only the effects of the obstacle nearest the antenna are considered. Thus, estimates made using this technique are optimistic in a case where the antenna points through two masts as can occur on shipboard.

This "open mast" technique is a good approximation when the percentage of antenna aperture which is blocked (shadowed) by mast members is less than 30%. Accurate analytical techniques for blockage percentages greater than 30% are not presently available.



"Best Case"



"Worst Case"

Figure 2 Open mast blockage.

2. Solid Mast Blocking Estimation Techniques

Estimates of solid mast blockage were obtained from the results of the far field antenna performance measurements of Reference 2. This reference contains measured data concerning the effects of flat sheet and cylindrical mast obstacles on antenna gain as a function of relative antenna and obstacle sizes and separation distance. A typical set of performance curves is shown in Figure 3. This figure shows the average boresight decoupling (i.e. gain loss) as a function of the angle between obstacle and target direction. The parameters shown in the figure are the obstacle distance (r) from the antenna aperture normalized in terms of far field units as $r/(2D^2/\lambda)$, the normalized obstacle width W/D where W is the obstacle width and D is the antenna diameter, and the polarization. The solid mast blockage estimates were obtained by interpolation of the data from several of these curves. It should also be pointed out that these measurements were made for an antenna elevation angle of 0 degrees. However these evaluations are an approximation for the blocking due to obstacles over a limited range of elevation angles of approximately $\pm$ 15 degrees.

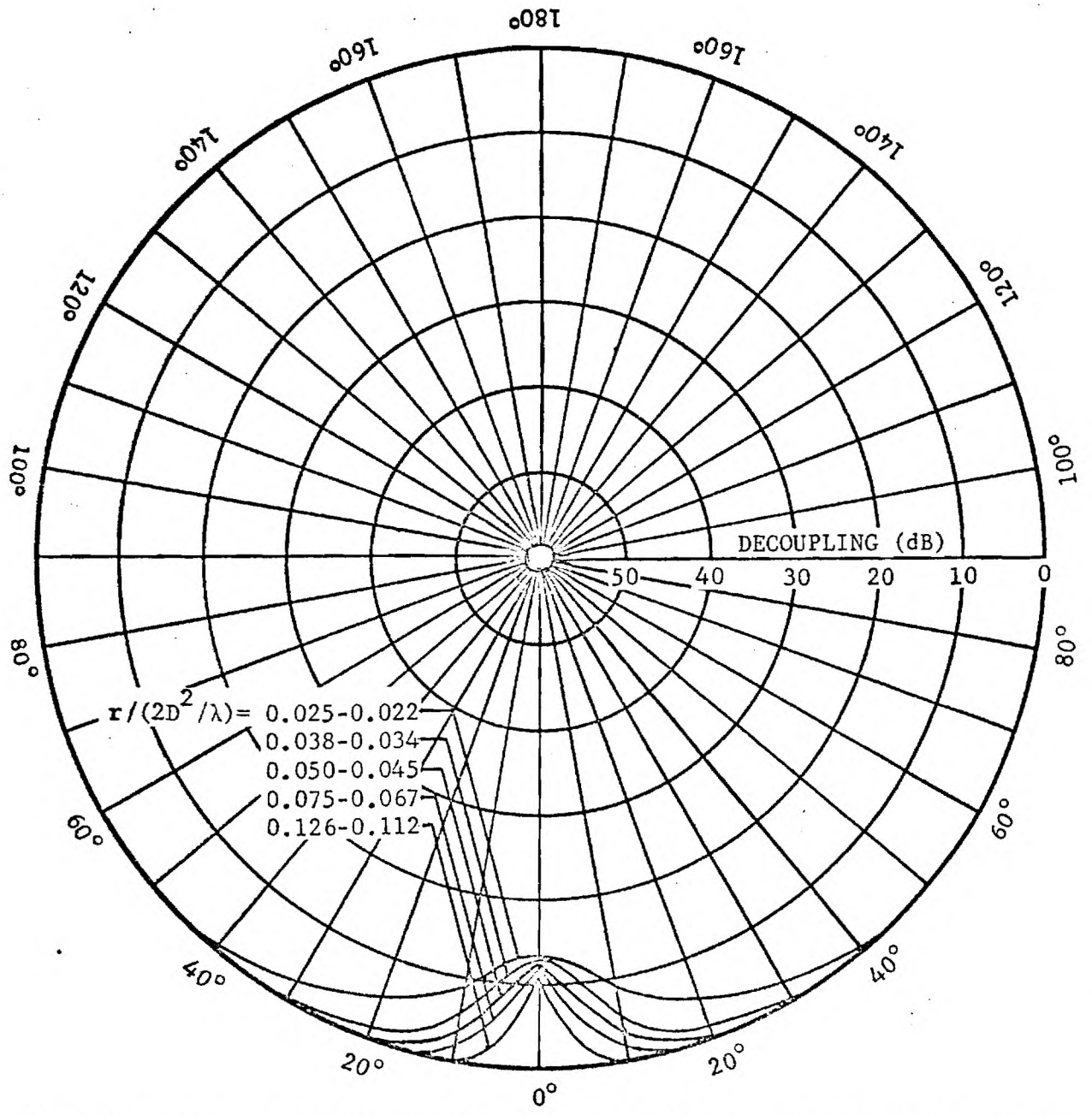


Figure 3 Average boresight decoupling as a function of the angle between obstacle and target direction for mast and sheet obstacles of normalized width 0.5 for indicated normalized obstacle distance from receiving antenna aperture D and for vertically polarized signals at frequencies of either 4900 or 5500 MHz.

APPENDIX II

ESTIMATION OF BLOCKAGE EFFECTS USING OPTICAL SHADOWING AND THE PHYSICAL OPTICS APPROXIMATION

The technique for estimating the blockage effects of support spars upon the antenna gain which was described in Appendix I is directly related to the technique of computing scattered fields using an optical shadowing approximation. Optical shadowing approximation for analysis of the scattering by an obstacle in the aperture of an antenna consists of determining the portion of the aperture which is blocked (i.e. shadowed) by the obstacle. The electromagnetic field is in the blocked portion of the aperture is assumed to be zero, to a first approximation. This zero field can be produced by removing the obstacle, and then superimposing an electromagnetic field on the aperture field which is equal to the negative of the aperture field. The blockage effects can then be obtained using superposition by computing the radiated fields due to the original aperture distribution and due to the assumed negative "blocked" aperture field. This procedure is depicted in Figure 4. Since the field which produces the shadow lies in the aperture plane, the "scattered field" due to the shadow can be computed as if this field were due to another aperture antenna. Thus aperture integration techniques and standard curves (3) can be employed to determine the field radiated (i.e. scattered) by this aperture distribution. Determination of the scattered field then reduces to calculation of the fields radiated by a "fictional" antenna with a specified aperture distribution and extent.

The above approximation is reasonable if the obstacle is close to the antenna aperture. However, if the obstacle is several aperture diameters removed from the antenna the current excited on the obstacle must be determined from a knowledge of the near zone antenna fields rather than from the assumed aperture distribution. This case is shown in Figure 5. The approximate surface current $\bar{J}s$ on the obstacle is assumed to be given in the physical optics approximation by (4).

$$\bar{J}s = \begin{cases} 2\hat{n} \times \bar{H}^{i} & \text{illuminated region} \\ 0 & \text{shadow region} \end{cases} \qquad (2)$$

where $\hat{n}$ is the outward normal to the surface and $\bar{H}^{i}$ is the incident

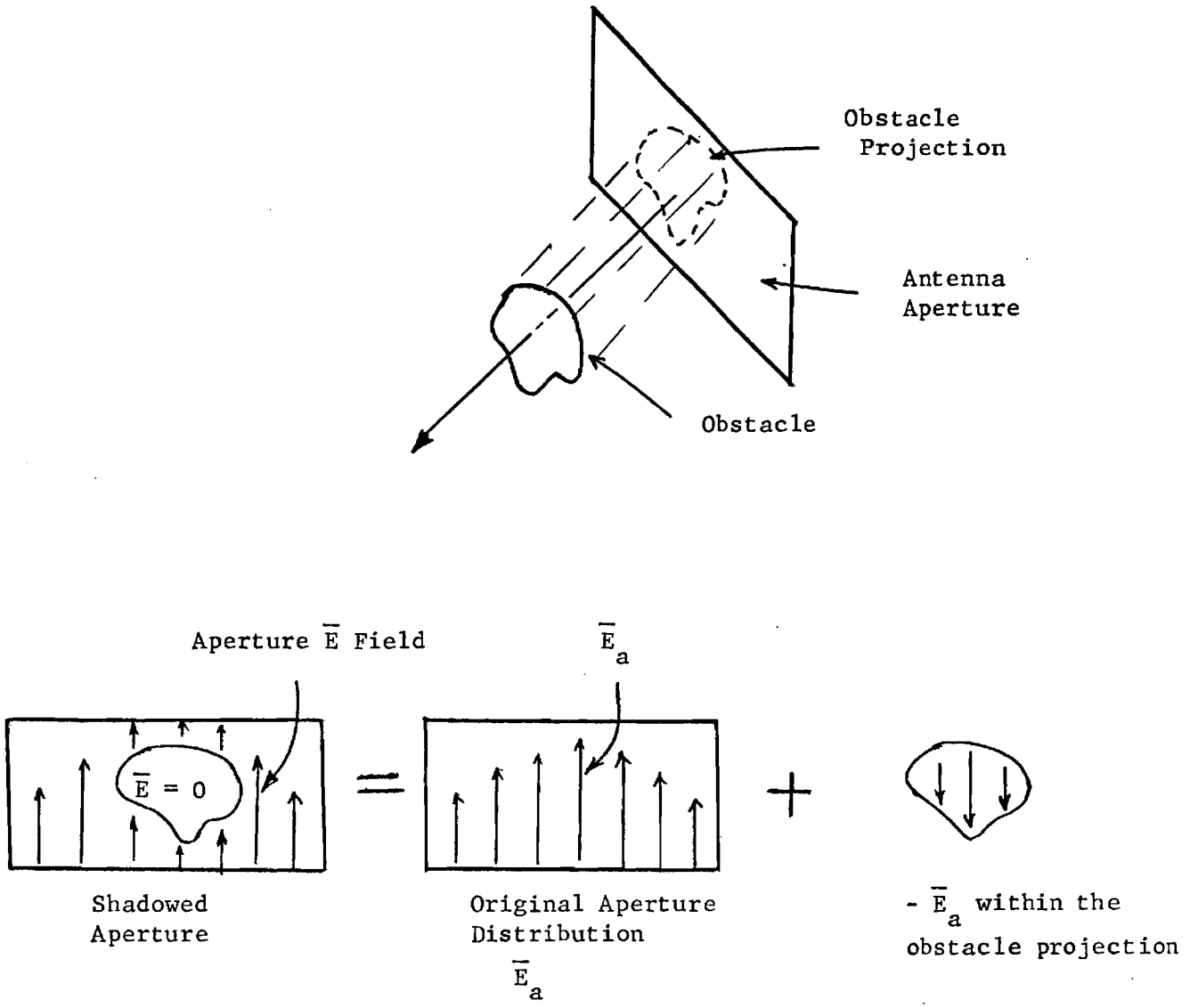


Figure 4 Illustration of the optical shadowing technique

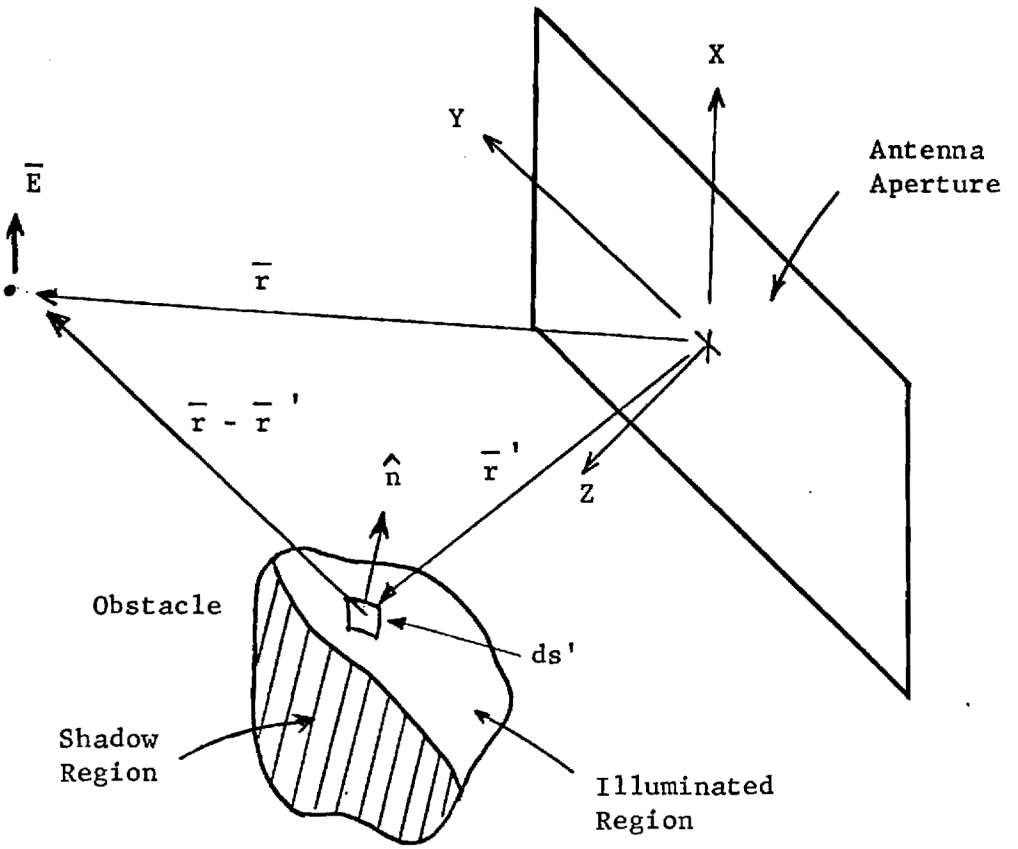


Figure 5 Coordinate System Used in the Physical Optics Analysis

near zone magnetic field evaluated on the surface. The scattered field $\bar{E}^s$ due to the assumed Physical Optics current is then given by

$$\bar{E}^s \approx \frac{1}{4\pi j\omega\epsilon_o} \nabla \times \nabla \times \int\int_s \frac{\bar{J}s\, e^{-jk|\bar{r} - \bar{r}'|}}{|\bar{r} - \bar{r}'|} ds' , \qquad (3)$$

where ω = 2π x frequency ,

ϵ_o = permittivity of free space ,

$\bar{r}$ = radial vector to the observation point, and

$\bar{r}'$ = radial vector to the differential surface element ds' .

The total field is the sum of the radiated antenna field with the obstacle absent ($\bar{E}_a$) and the scattered field ($\bar{E}_s$) viz,

$$\bar{E}_{tot} = \bar{E}_a + \bar{E}^s . \qquad (4)$$

The physical optics approximation has been shown to be accurage for flat-plate obstacles which are removed from the antenna aperture but which are lócated within the near zone of the antenna (5).

An advantage of the physical optics approximation over the optical shadow method is that the shape of the scatterer is accounted for by the assumed surface currents. Thus the reflected fields due to the obstacle can be computed using the physical optics approximation whereas the reflected fields, in general, cannot be obtained using the optical shadow approximation.

A characteristic of both approximations is that they are reasonably accurate in the main beam region. However the accuracy decreases with increasing angle in the side lobe regions. The physical optics approximation is also accurate in the regions of specular reflection.

Due to the complexity of the topside structures on the PF, it was not feasible to implement a physical optics analysis on the computer. However this technique might be applied in the future if a suitable, general computer algorithm is developed. One difficulty in implementing a general physical optics program is the lack of an efficient computer algorithm for the determination of the near zone fields of the antenna.

The estimates of the blockage effects of the top-of-the-mast structures on the performance of the AN/SPS-49 radar antenna were thus made using the optical shadowing technique. When the projected area of these top-of-the-mast structures on the antenna aperture was relatively small the blockage equation of Appendix I or standard curves (3) for gain loss and sidelobe levels due to blockage could be used.

Since the percentage of aperture blocked is a function of elevation angle, it is necessary to determine the shadowed area as a function of elevation angle. This can be done by referring to the topside design drawings, or through the use of the Shipboard Siting of Antennas Computer Algorithm (6,7).

These techniques are useful when the percentage of the aperture blocked does not exceed approximately 30%. When the aperture blockage exceeds 30% the experimental data presented in Reference 2 can be used to obtain gross estimates of the antenna gain loss. This data has been incorporated in the Shipboard Siting of Antennas Computer Program (8) for automatic computation of antenna gain loss for aperture blocking ratios between approximately 20% and 100%. However, a lack of an extensive data base limits the usefulness of this computer algorithm.

APPENDIX III

EFFECTS OF MULTIPLE MASTS

The analysis of the electromagnetic blocking and scattering effects of the ship topside structure is a very complicated problem due to two facts. First, the structures to be analyzed are complex objects for which rigorous scattering solutions are neither available or possible. Second, the topside structure is composed of a multiplicity of scattering structures. This makes an exact analysis unfeasible and thus dictates that approximate analyses be developed. In particular, for the Patrol Frigate, a two mast structure must be considered in the estimation of the radar antenna coverage performance. In order to estimate the effects of the two open mast structures on the PF radar antenna coverage an approximate analysis was developed. This technique will be described in detail in this appendix.

The far-zone scattering by two cylinders has been treated by a number of authors (9, 10, 11). Recently, extensive results for the scattering by multiple spheres (12, 13) have been presented. These studies have generally considered only the case of plane wave incidence, that is, the usual far-zone scattering situation. This far-zone situation is not typical of the scattering by multiple mast structures on shipboard, since the mast structures are typically in the near-zone of the radar antennas. However, some useful information may be derived from these far-zone results, which in conjunction with measured near-zone results (2) permits an estimation of the effects of such multiple structures upon the antenna main-beam gain.

For the case of two cylinder scattering of an incident plane wave, Olaofe (9) states that when two identical cylinders are colinear with the incidence direction (the "endfire case"), the total scattering is nowhere less than twice the corresponding single cylinder scattering. [Note: The scattering cross section of an object in a given orientation is 4π times the ratio of the radiation intensity of the scattered wave in a specified direction

to the power per unit area in an incident plane wave of a specified polarization. The total scattering cross section is the ratio of the total scattered power to the power per unit area in the incident plane wave.] He also observes that when two identical cylinders are aligned perpendicular to the incidence direction, (i.e. the "broadside case") the total scattering cross section oscillates about a value equal to twice the total scattering cross section of the isolated scatterer. Similar conclusions for the backscatter and forward scatter cross sections have been advanced by other authors (11, 12, 13). The magnitude of the oscillation of the backscatter and forward scatter cross sections for both of the cylinder configurations decreases with increasing cylinder separation. However, the results of Olaofe (9) show that the oscillation of the forward scattered field about its mean value is relatively insensitive to the cylinder separation, whereas the oscillation of the backscattered field about its mean value is extremely sensitive to cylinder separation. Since the case of primary interest for the Patrol Frigate geometry currently is the case of forward scattering, we will assume that the mean value of the forward scattering cross section of the multiple masts can be used to estimate the antenna gain loss and that interactions can be neglected.

As an approximation we assume that the total forward scattering cross section σ_{TF} for the case of plane wave incidence on two identical cylinders can be expressed as

$$\sigma_{TF} = 2\ \sigma_{FS} \quad , \tag{5}$$

where σ_{FS} is the forward scattering cross section of a single cylinder. The forward scattered electric field, $E_{FS}(r)$ at range r from the scatterer, is proportional to the square root of the forward scattering cross section. For the case of plane wave incidence, $E_{FS}(r)$ is given by

$$E_{FS}(r) \alpha \quad \sqrt{\frac{\sigma_{TF}}{4\pi}}\ \frac{E^i}{r} \ ,$$

where E^i is the incident electric field.

As previously noted, the antenna mast configurations occuring for the Patrol Frigate are near-field configurations. In the near-field, the scattering cross section is a complicated function of the antenna aperture distribution, the antenna/scatterer configuration, incidence angle, wavelength, and polarization. Very little information is available regarding the characterisitcs of the near-zone cross section.

Because no data regarding the near-zone forward scattering cross section exist, the measured antenna boresight gain reduction curves for cylindrical masts presented in Reference 2 have been used to deduce an approximation for the near-sone scattering cross section. Consider the configuration shown in Figure 6 , where a cylindrical obstacle is in the near zone of the antenna aperture. The incident field $E^i(r)$ from the antenna is assumed to be given by

$$E^i(r_s) = \frac{G_{NZ}(r_s)}{\sqrt{4\pi}} \quad \frac{e^{-jkr_s}}{r_s} \cdot (1 \text{ volt}) \quad , \qquad (6)$$

where r_s is the range between the antenna and the obstacle, $G_{NZ}(r_s)$ is the near-zone boresight voltage gain of the antenna, and $k = 2\pi/\text{wavelength}$. Curves of the near-zone boresight gain of rectangular and circular aperture antennas are given in Reference 4. Curves of the near-zone gain for a variety of aperture distribution have been calculated and are available (14). The forward scattered field is proportional to the square root of σ_{FS} and to the near zone voltage antenna gain. The forward scattered field $E_{FS}(r)$ at range r is given by

$$E_{FS}(r) = \frac{\sqrt{\frac{\sigma_{FS}}{4\pi}}\, e^{-jk(r-r_s)}}{(r-r_s)} \quad E^i(r_s) \quad . \qquad (7)$$

The total far-zone field $E_T(r)$ at a great distance r for the case when the antenna boresight axis is directed toward the center of the obstacle as shown in Figure 6 is given as

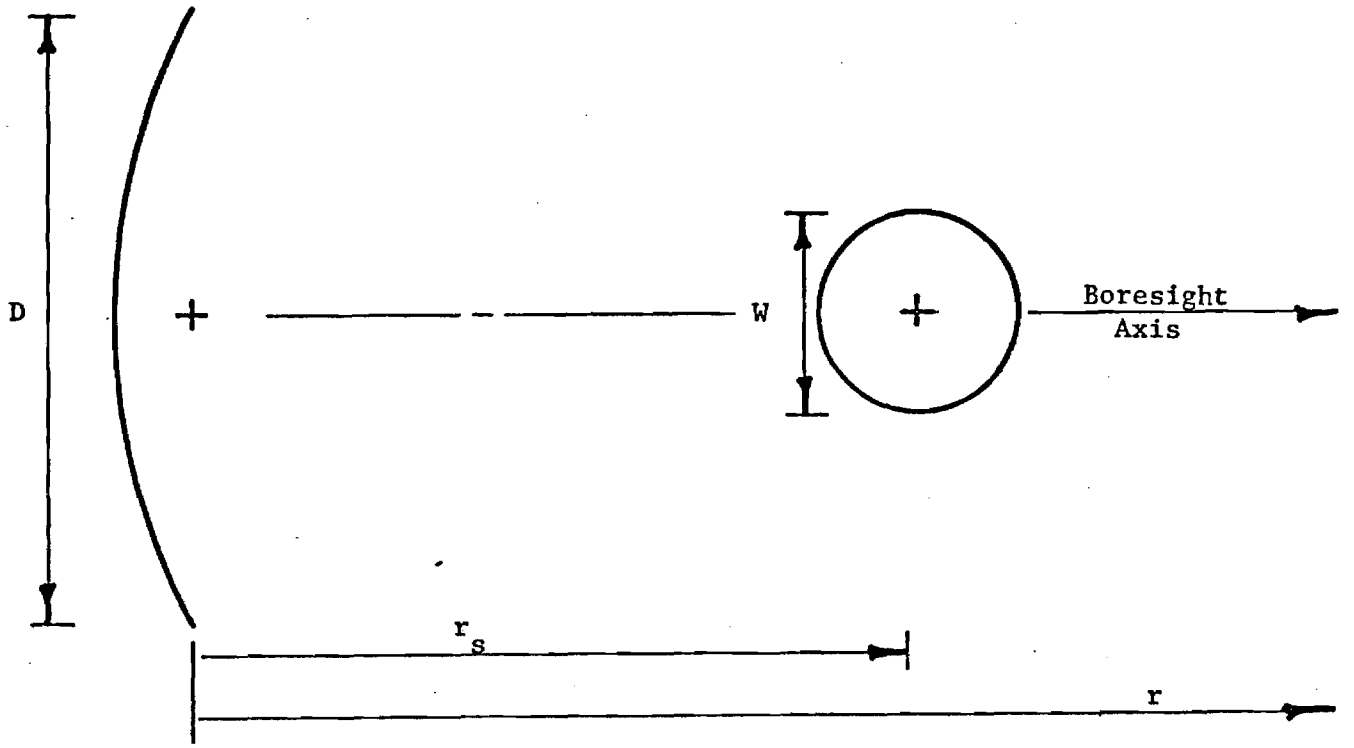


Figure 6 Cylinder-antenna geometry for antenna gain reduction estimations.

$$E_T(r) = E^i(r) + E_{FS}(r) = \left\{ \frac{G_{FZ}}{\sqrt{4\pi}} \frac{e^{-jkr}}{r} - \frac{\sqrt{\frac{\sigma_{FS}}{4\pi}}\, e^{-jk(r-r_s)}}{(r-r_s)} \right.$$

$$\left. \cdot \frac{G_{NZ}(r_s)\, e^{-jkr_s}}{\sqrt{4\pi}\, r_s} \right\} \cdot (1 \text{ volt}) \quad , \qquad (8)$$

where G_{FZ} is the far-zone antenna voltage gain. For $R >> r_s$ Equation 8 reduces to .

$$E_T(r) = \left(G_{FZ} - \frac{\sqrt{\frac{\sigma_{FS}}{4\pi}}}{r_s} G_{NZ}(r_s) \right) \frac{e^{-jkr}}{\sqrt{4\pi}\, r} \quad . \qquad (9)$$

The one-way voltage gain reduction R_v is given by

$$R_V = \left(G_{FZ} - \frac{\sqrt{\frac{\sigma_{FS}}{4\pi}}\, G_{NZ}(r_s)}{r_s} \right) \frac{1}{G_{FZ}} \quad . \qquad (10)$$

The above approximate equations are not accurate if the near-zone forward scattering cross section is a complicated function of the antenna aperture distribution and/or of the antenna-obstacle range. In order to evaluate the usefulness of Equation 7 , the measured results of Reference 2 and the near-zone gain reduction curves of Reference 3 were used in conjunction with Equation 7 to calculate approximate values for σ_{FS}. Two approximate techniques were examined for evaluating the near-zone forward scattering cross section σ_{FS}. The approximations consisted of matching the analytical expression for the gain reduction given in Equation 7 with measured gain reduction results. The first approximation defined a value for σ_{FS} by matching Equation 7 and measured results for an antenna-obstacle separation distance of 0.126 $(2D^2/\lambda)$. (D = antenna diameter, λ = wavelength). $(\frac{2D^2}{\lambda})$ is the usual far-zone range criterion. The second approximation consisted of matching the data and Equation 7 at five antenna/obstacle separation distances to determine five values of the near-zone forward scattering cross section. Next the "average cross section" σ_{AVE} was computed by taking the

average of these five values. If the forward scattering is relatively insensitive to the near-zone antenna/obstacle separation distance, the average value σ_{AVE} is expected to be a good approximation for computing the gain reduction. The values of σ_{FS} defined by comparison at 0.126 $(2D^2/\lambda)$ is expected to be a good approximation when the antenna/obstacle separation distance exceeds 0.126 $(2D^2/\lambda)$. Figures 7 and 8 show the results of these approximations. In Figures 7 and 8 the results of the two approximations are shown as dashed lines, the circles depict the measured data and the solid straight are an approximate "best fit to the measured data". Figure 7 shows the results for both horizontal and vertical polarization for a 6-inch diameter cylinder blocking a 48-inch diameter circular aperture at an operating frequency of 4900 MHz. For this relatively small cylinder, both approximations are reasonably accurate. Similar curves at 4900 MHz are shown in Figures 8a and 8b for horizontal and vertical polarization, respectively, for a 24-inch diameter cylinder blocking the 48-inch diameter aperture. In the case of the 24-inch diameter cylinder, the average value cross section σ_{AVE} yields better results for separation distances less than 0.1 $(2D^2/\lambda)$ and the value of σ_{FS} defined by matching at 0.126 $(2D^2/\lambda)$ is more accurate at larger separation distances. However, even for the 24-inch diameter cylinder, the approximate analyses are within 2.5 dB of the measured values. The accuracy of the zpproximation for the 6-inch diameter cylinder is much better, being within 1 dB.

A conclusion which can be drawn from the above results is that for moderate values of gain loss between zero and approximately 10 dB, the relation given in Equation 7 is an useful approximate description of the near-zone forward scattering. The approximate formulation is not accurate when the gain loss caused by obstacle blockage is sensitive to the antenna-obstacle separation distance. The gain loss is very sensitive to this separation distance when the obstacle width exceeds approximately 50% of the aperture diameter and is moderately sensitive to separation distances for obstacles exceeding 25% of the aperture diameter. Also the effects of complex scattering obstacles may not be similar to the results obtained for the cylindrical obstacles. Further study of these more complex cases is required.

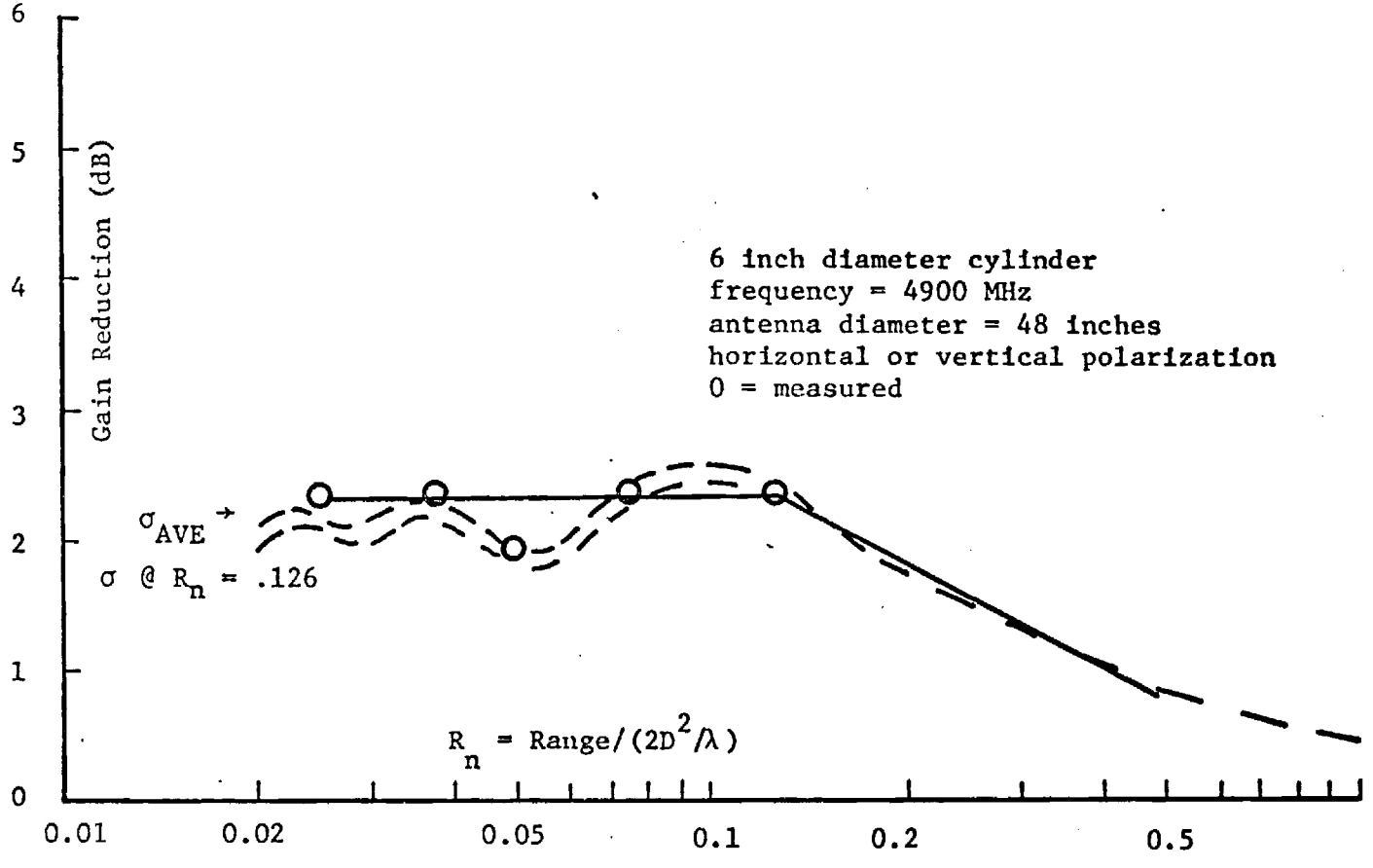


Figure 7 One-way, main-beam antenna gain reduction for a 6-inch diameter circular cylinder blocking a 48 inch diameter paraboloidal antenna.

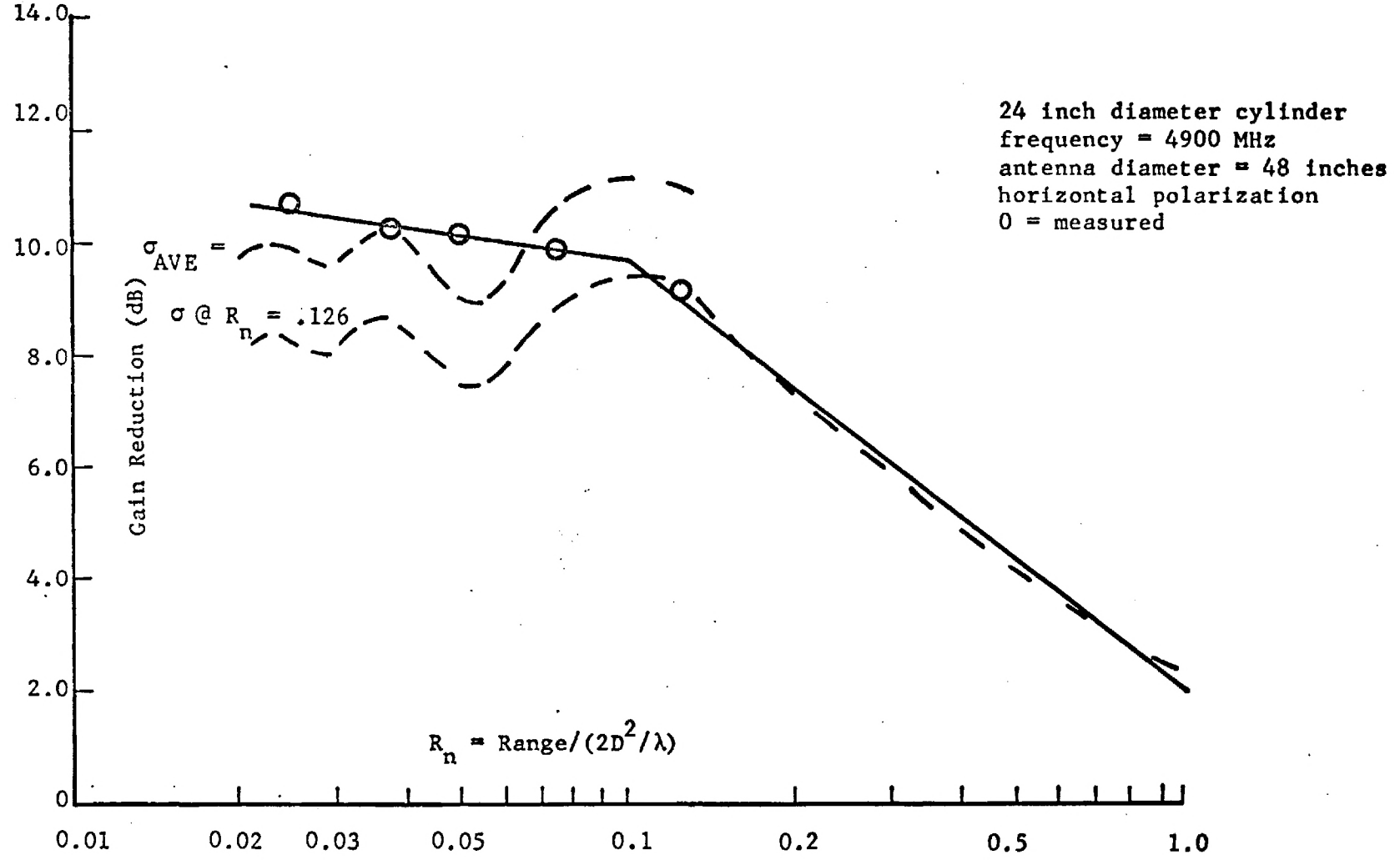


Figure 8a One-way, main-beam antenna gain reduction for a 24-inch diameter circular cylinder blocking a 48 inch diameter paraboloidal antenna - horizontal polarization.

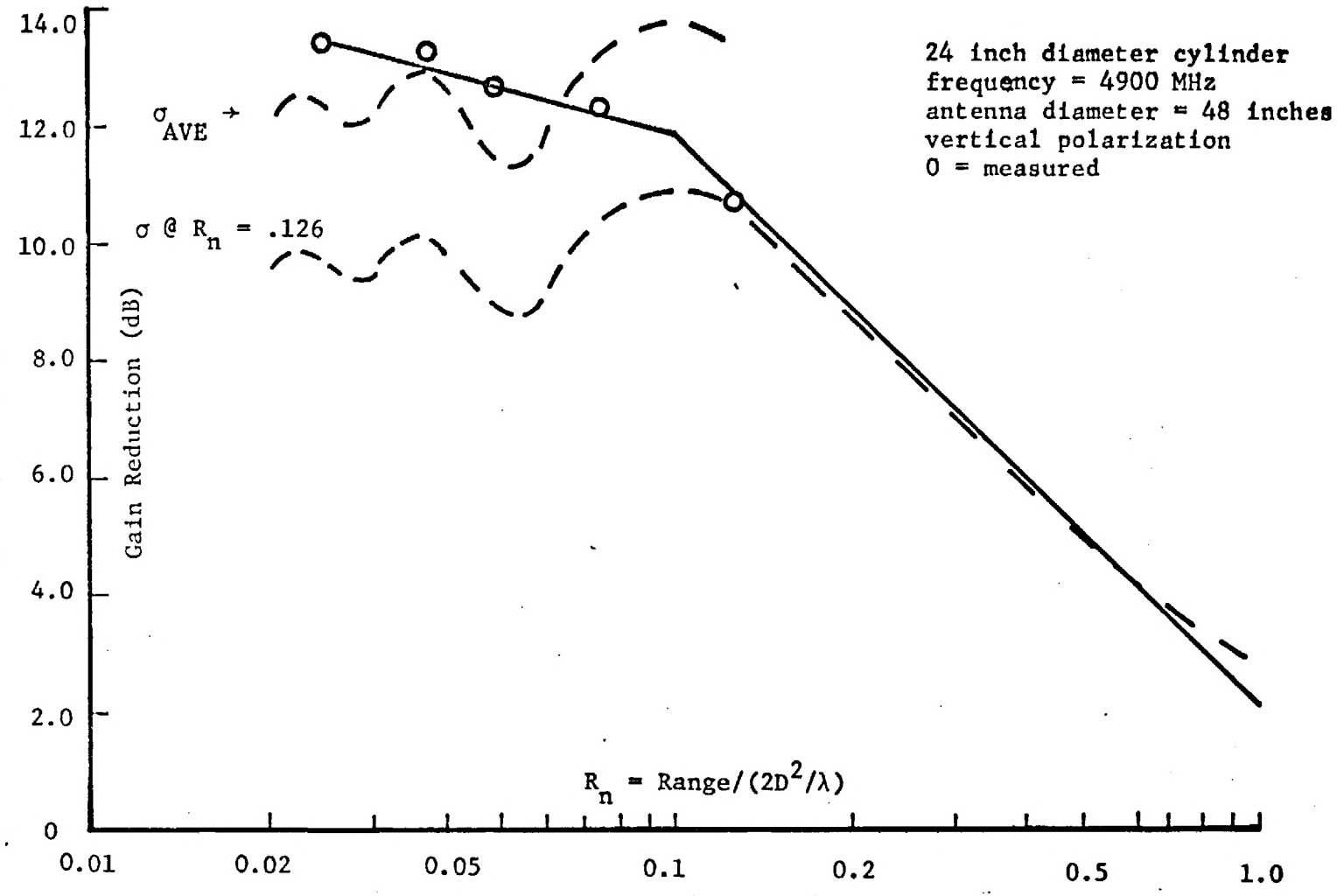


Figure 8b One-way, main-beam antenna gain reduction for a 24-inch diameter circular cylinder blocking a 48 inch diameter paraboloidal antenna - vertical polarization.

The near-zone results for the single cylinder may be generalized by analogy with the are-zone scattering results previously cited. That is, in the forward scattering direction only, the near-zone scattering cross sections will be assumed to be constant with antenna-cylinder separation, and the scattered fields are assumed to be additive in such a manner as to produce the maximum (i.e. worst case) gain reduction. With these assumptions, the gain loss for two obstacles is taken as

$$R_V = \left(G_{FZ} - \frac{\sqrt{\frac{\sigma_{FS1}}{4\pi}}\, G_{NZ}(r_{s1})}{r_{s1}} - \frac{\sqrt{\frac{\sigma_{FS2}}{4\pi}}\, G_{NZ}(r_{s2})}{r_{s2}} \right) \frac{1}{G_{FZ}} , \quad (8)$$

where the subscripts 1 and 2 denote the two obstacles, and r_{s1} and r_{s2} are the ranges from the antenna to each of the obstacles.

The gain loss formula given by Equation 8 can be extended for calculation for more than two obstacles by the addition of appropriate terms corresponding to the additional obstacles.

The procedure for the estimation of the gain loss due to multiple obstacles is thus straightforward. First the forward scattering cross section of each individual obstacle is obtained from analysis or measured data. Second, the near zone gain of the antenna corresponding to each of the obstacle ranges is computed or obtained from standard curves. Third, the reduction is computed using the approximate equation.

This approximate analysis is based upon limited theoretical and measured information. The subject of the near-zone scattering by multiple complex obstacles requires further theoretical and experimental effort before accurate, high confidence level, predictions of antenna gain loss can be made.

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